Combined extended two point Dixon/Look Locker technique for mapping of lipid spin-lattice (T1) relaxation time

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TARGET AUDIENCE: Investigators who are interested in applications of fat/water imaging and T1 measurement, and the methods to monitor tumor hypoxia.

INTRODUCTION: Tumor hypoxia is a main problem arising in the treatment of cancer due to its resistance to radiation therapy and chemotherapy, and selection for more aggressive tumor phenotypes. Attempts to improve and quantify tumor oxygenation are in development and tools to assess the success of such schemes are required. Monitoring oxygen level with MRI using a T1 based method (where oxygen acts as T1 shortening agent) is a dynamic and noninvasive way to study tumor characteristics [1]. The method's sensitivity to oxygen is higher in lipids than in water due to higher oxygen solubility in lipids [1]. Our study aims to develop a time-efficient method to spatially map the T1 of fat inside the tumor. We are combining two techniques: Fat/Water imaging and Look Locker (LL) [2] (a rapid T1 measurement technique). Fat/Water Imaging is done using the extended two point Dixon [3]. The combination of these techniques poses new challenges that are tackled using spin dynamics simulations as well as experiments in a phantom and mouse in vivo.

METHODS: For accurate measurement of T1, the optimal values of flip angle (α) and time between consecutive flip angle pulses (τ) for the LL method were determined from a Monte Carlo simulation to be {35°, 80ms} for T1 ~ 200ms. The spin dynamics of the combined extended two-point Dixon/LL method were studied using 3D Bloch's simulation to understand the behavior of water and fat signals.
To verify the simulation, we first performed the combined extended two point Dixon/LL method in a phantom (results not shown), and subsequently in a mouse in vivo. The low abdomen/thigh region of an obese black mouse was scanned for two different echo times (FLASH; flip angle=35°; TR/TE={80/1.924 (4); 80/2.405 (5);}; matrix=128x64x28; FOV=2.5x1.5x3.45; Hermite pulse excitation, non-selective hard inversion pulse on resonance with dominant fat signal as determined from single voxel spectroscopy; Total Inversion Recovery Time: 3240ms (2240ms (recovery time)+ 1s (waiting time before the next inversion pulse))) using optimal values of α and τ. The experiments were carried on a Biospec 70/30 scanner (Bruker, Germany) with a volume coil transmit/ surface coil receive. The total scan time for each echo time was 15.5min with four number of averages. Studies were approved by the animal care research board.

RESULTS & DICUSSION: In-phase and out-of-phase images of the low abdomen/thigh region are shown in Figure 1. In subcutaneous fat region (region 1), both fat and water signals are expected, whereas in femoral muscle region (region 2), water signals are dominant (Figure 1). The T1 recovery curves for pixels at those two regions show, as expected, both water and fat signals in the subcutaneous fat region, and almost no fat signal in the femoral muscle region (Figure 2 top right and middle right). T1 of fat in subcutaneous fat was 442ms. Since the pulses were on resonance on fat, we did not calculate T1 of water here (T1 estimation depends strongly on the flip angle). Our main interest was focused on T1 of fat. The low signal in external oblique muscle of out-of-phase image (Figure 1 right, region 3) indicates the typical ratio of fat and water signal. The low signal of the out-of phase data leads to a swap of fat and water signals due to the error in the estimation of phase factor in the extended two point Dixon method. As a result, swaps of fat and water T1 were observed in this region. This problem shows the limitation of the extended two point Dixon method. To solve this problem, fat/water imaging techniques that uses more than 2 different echo shifts are required (i.e. 3 point Dixon [4],[5], Direct Phase Encoding [6]).

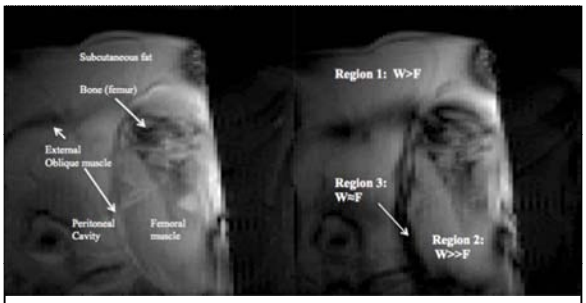
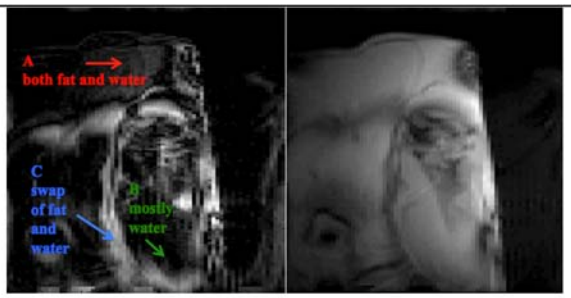


Figure 1. In-phase and out-of phase images with TE=1.924ms (4π (left)) and TE=2.405ms (5π (right)) of the first frame along the recovery curve.

CONCLUSION:
Here we proposed a rapid T1 measurement of fat, by combining the extended two point Dixon and LL. We have successfully employed the technique in-vivo to spatially map T1. Although, we observe swaps of fat and water T1 in some regions where water and fat occur at similar intensity, we can resolve this ambiguity with the help of the obtained T1 in the Look Locker inversion recovery curve.



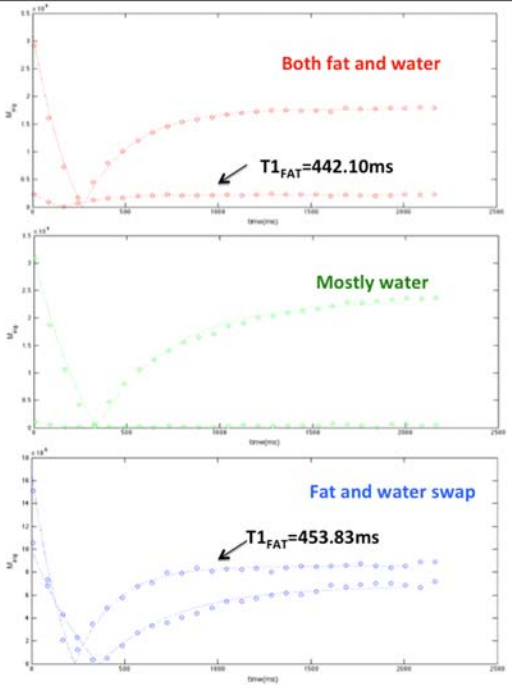


Figure 2. Fat (above left)/ Water (above right) images of two point extended Dixon/LL method (first frame along the recovery curve) and pixel-level recovery curves from each image from three different tissue compartments (left).
Arrows in fat image indicate the pixel location of fat/water recovery curves on the right (pixel A,B,C).
Pixel A: water recovers slower compared to fat.
Pixel B: water signal dominates. T1 of fat cannot be estimated due to limited signal.
Pixel C: This is where a swap of fat and water signals occurs. Fat image generates T1 recovery of water and vice versa. In this figure, curves are labelled correctly taking into account expected relaxation times of fat and water, respectively.

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